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Enhancement of Mechanical Properties of Alloy Steel by GTAW with Different Purge/Shielding Gases

Welding of ferritic steel tube material T91 (9Cr-1Mo), was used because of high temperature withstanding, mechanical properties, compatibility with chemicals and adequate weldability. The main objective of this project is to find out near optimum welding parameters with appropriate shielding gas in gas tungsten inert gas welding (GTAW) of T91 tube. The quality and productivity of the weld joint strongly depends on welding parameters. The perfect arc during welding is produced when the welder uses the optimum welding parameters. The composition of shielding gas plays an important role ensuring sound quality of welds. The composition of shielding gas with the molten pool has a marginal influence in the depth of penetration. The optimized parameters with three samples were prepared with different purging gases Viz. 100% helium, 100% Argon, Argon 50% plus Helium 50% for welding of 2.9 mm thick T91 tube with ER 505 filler wire.

Keywords : *T91, GTAW, Purge Gas, Shielding gas, ER 505.*

1. INTRODUCTION

Welding of the ferritic low alloy steel is widely used for fabricating components for the nuclear power plants, thermal power plants, refineries, chemical plants and other industries. The low alloy steels are generally joined by gas tungsten arc welding (GTAW) for the thinner sections, where as the thicker sections are joined by shield metal-arc welding (SMAW) [1].

In conventional arc welding, the base metal is heated to molten state so that the metal may join together by using fusion welding. An electrode or filler is added in the heated zone, which leads to replace metal consumed by the process and to produce a reinforcement area on both internal and external surface based on the weld joint configuration. In arc welding process, high-current and low voltage are applied to produce the arc, which hits in between the work metal and the end of the electrode work, generating the intense heat that immediately melts tile surface. The several variables, such as composition of base material and its size, equipment, fluxes, gases, electrodes, degree of skill, and strength requirements affect the quality of the sound welds [2]. There are many welding and allied welding processes followed around the world. Among these, gas metal arc welding (GMAW), flux-cored arc (FCAW), shielded metal arc (SMAW) and gas tungsten arc welding (GTAW) are widely used for repairing the base metal and structural application, where special shielding gases, such as argon, helium, mixture of helium and argon, carbon di oxide etc., are used in order to protect the weld from oxygen and nitrogen from atmosphere. In SMAW and FCAW, flux is used to protect the weld metal from oxygen and nitrogen [3].

GTAW is substantially applied in the fabrication of nuclear and chemical plant and in the manufacture of aerospace engine components. In GTAW, Workpieces are merged together, when heat produced in the form of arc from the non consumable electrode tungsten, touches the workpiece with sufficient heat [4,6]. The shielding and purge gas have great influence in the heat input, residual stress on weld, HAZ and microstructure of the weldment [5]. The shielding gas (Ar, He, H2, N2, etc.) is used to avoid atmosphere contamination of the molten weld pool and filler metal may be added if required. It is the cleanest of the arc welding processes [7]. However, despite being a precision welding process, problems are frequently experienced in maintaining a uniform degree of penetration. These difficulties may occur as a result of variations in the process parameters (material dimensions), welding parameters (current, voltage, torch speed, electrode-work piece distance, electrode dimensions, shielding gas composition and flow rate), material composition (cast-to-cast variations) and welder skill.

In this study, the experiments were carried out to determine the effects of different shielding and purge

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gases, such as, Argon, Helium and the mixture of Argon and Helium in GTAW process to enhance the weld properties of alloy steel T91 material. This study also discusses the relationship between the mechanical strength and microstructures of the GTAW process with different gases. Molecular atomic weight of Argon inert gas is 40. Being noble element, the refined argon can have the purity of at least 99.95% during gas tungsten arc (GTAW) welding process. Argon, as a shielding gas in gas tungsten arc welding (GTAW) process, can produce better surface finish, better quality, reduced penetration, smoother and quieter arc action. Molecular atomic weight of helium is 4. Helium is also an inert gas. Refined helium has a purity of at least 99.99%. For the same welding parameters (like welding current, welding voltage, welding speed etc.), helium produces more heat than argon having potential to joining the thicker and heavy plates, and welding the metals of high thermal conductivity [6,7]. Mixing of argon and helium gases can offer the relative advantages of both helium and argon gases. An appropriate composition of helium and argon can raise the temperature, support for high welding speed and provide deep weld penetration [7].

2. EXPERIMENTAL SETUP

The T91 wall tubes of size 125 mm long, 33.7 mm diameter and 2.9 mm thick were selected for the investigation. The GTAW welding of non-consumable tungsten electrode and ER505 (1.6 mm diameter) were used. The chemical composition of T91 and ER305 are given in table 1. Argon, helium and mixture of helium and argon gases were used as shielding and purging gas for welding. The machined components are cleaned to remove oil, dust and other impurities and are dried.

Table 1: Chemical Composition of Alloy steel T91

Elements	C	Si	Mn	P,S max	Cr	Mo	Ni	V
% of wt for T91	0.1	0.25	0.45	0.01	9	0.98	0.4	0.21
% of wt for ER505	0.11	0.45	0.55	0.02	10	1.01	0.45	Cu 0.73

The thin wall tube was loaded in a welding fixture and purging and shielding arrangements were made. Before welding in GTAW, preheating was performed with the temperature ranging from 200-250°C.The welding was carried out in two passes. Upon completion of root pass visual inspection was done. Furthermore, root pass DPT examination was done.

Figure 1: Pre heating the test specimen

The second final weld pass was carried out with sufficient weld reinforcement. The welding process is shown in figure 1. The temperature was measured by using pyrometer. The pulsed GTAW welding was performed with the welding power source for selected parameters. The welding parameters of this work are given in table-2 in Annex-1. After the completion of welding, all the test specimens were undergone for a post weld heat treatment under the loading temperature of 300 °C, the heating and cooling rate of 150 °C, the soaking temperature of 750 °C and the soaking time of 30 minutes.

3. RESULTS AND DISCUSSIONS

2.1 Mechanical Strength

The tensile strength properties like ultimate tensile stress, yield stress, Ultimate load & yield load, of the GTAW weld were examined. The tensile test specimens were prepared as per the ASME sec IX standard [8]. The yield strength and tensile strength of the argon gas weld specimen were found to be 485MPa and 640 MPa respectively. But the yield strength and tensile strength of the helium gas weld specimen are 498 MPa and 653 MPa respectively. Therefore, as compared to pure helium gas, pure argon is not considered good as a shielding and purge gas for welding of T91 alloy steel. Correspondingly, the weld specimen produced under the atmosphere of the mixture of argon (50%) and Helium (50%) gases exhibited the yield strength and ultimate strength of 494 MPa and 645 MPa, respectively. These values are higher than the argon gas weld specimen, but slightly lower than the pure helium gas welds specimen. Hence, the maximum tensile strength was obtained from the helium gas test specimen comparing with the pure argon as well as the mixture of argon & helium gas.

2.2 Microhardness

Figure 2 represents the graphical form of micro hardness values across the welded portion measured in a Vickers microhardness tester. X-axis represents the distance in mm and Y-axis represents the microhardness number.

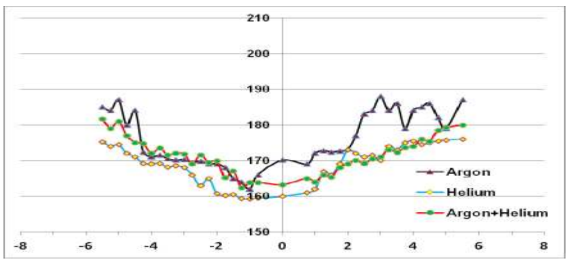


Figure 2: Micro hardness for different shielding gas

For repeatability and accuracy of the micro hardness results, the sample protection from environment and surface roughness are very much important. Irregular surface reduced the repeatability and accuracy of the micro hardness results because of the irregularities of surface.

2.3 Residual Stress

Figure 3 represents comparison of the residual stress for welded pieces. Testing of residual stress was studied using

X-ray diffraction analysis. The residual stresses of the weld specimens were recorded and presented in the graphical form as shown in figure 3. Y-axis represents the residual stress (MPa) and X-axis represents the distance from the weld center mm.

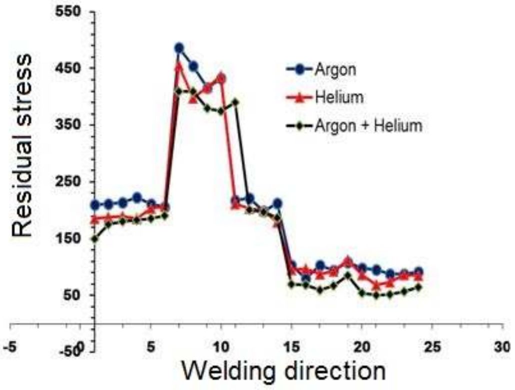
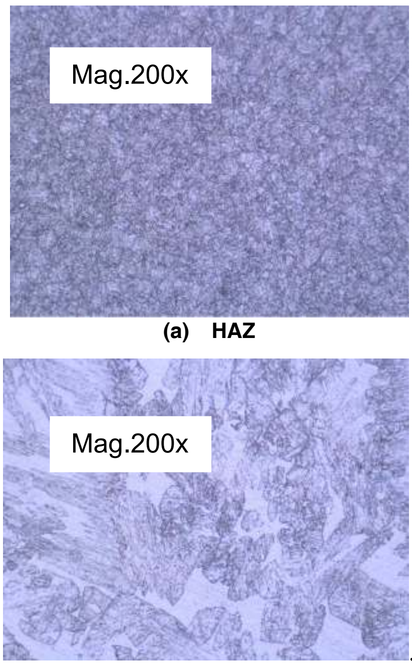


Figure 3: Residual stress comparisons

The maximum residual stress was observed in pure argon (487 MPa), followed by argon plus helium mixture (450 MPa) and the least residual stress in pure helium (410 MPa). Helium test specimens showed better result in terms of residual stresses as compared to the specimens exposed to argon as well as argon plus helium mixture. This is because of helium's higher thermal conductivity that could dissipate more heat faster.

2.4 Microstructure

The optical micrographs of weld test samples are presented in Figure 4, 5 & 6 respectively. All micrographs are presented in 200 X magnification in a light microscopy. It should be noted that the T91 base metal primarily consists of ferrite grains [9]. The objective of any welding is to provide the weld specimens without considerable variation in grain size observed between the weld region and heat unaffected region.

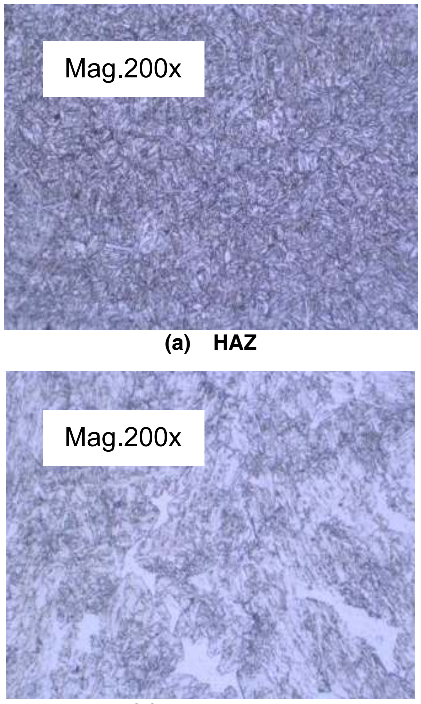


(a) HAZ

(b) Weld Metal

Figure 4: Microstructure of Argon gas specimen HAZ &WM

Figure 4 indicates the microstructure image of argon gas specimen HAZ and weld metal (WM). It showed the tempered martensitic structures with reduction in grain size. Argon gas, having heavier density and low thermal conductivity, dissipated the heat into the base material and nearer to the heat affected zone (HAZ) leading to refinement of weld metal grain size, decrease in width of heat affected zone (HAZ) and control of segregation. These factors improved the mechanical properties of the welded region [10].

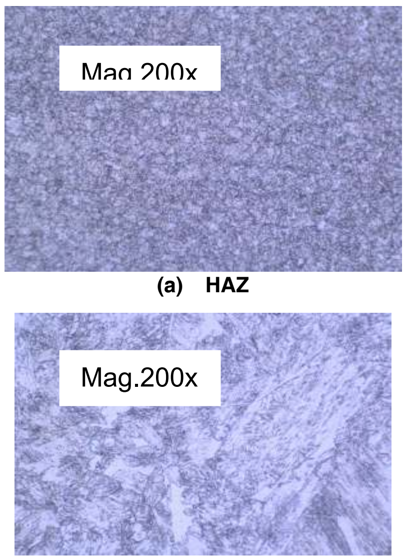


(a) HAZ

(b) Weld Metal

Figure 5: Microstructure of Helium gas specimen HAZ &WM

Figure 5 indicated the microstructure of the helium gas specimens in HAZ and weld metal (WM). It showed the tempered martensitic structures, while retaining the delta ferrite in the WM as a result of cooling after welding at room temperature. Delta ferrite can have detrimental effects on the mechanical properties [11].



(a) HAZ

(b) Weld metal

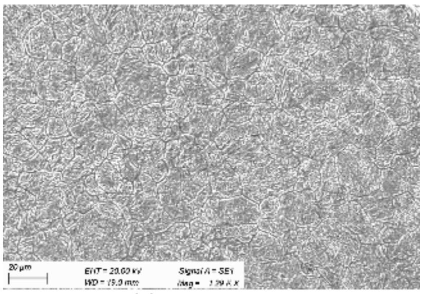
Figure 6: Microstructure image of Argon 50% & Helium 50% gas specimen HAZ and WM

Figure 6 indicated the microstructure of the argon plus helium gas mixture specimen in HAZ and weld metal (WM). It showed the tempered martensitic structures in HAZ and weld metal with the mixture of ferrite and austenite [12].

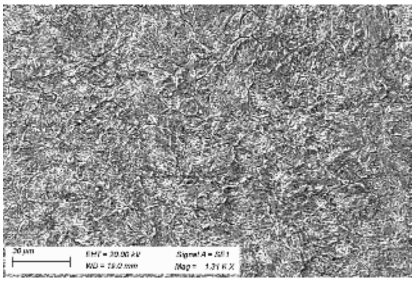
2.5 Scanning Electron Microscopy

The SEM examination was conducted on all welded specimens. The weld specimens were mirror polished up to 2000 girt and the specimen's surface was etched in Nital etching solutions.

The base metal T91 mainly consisted of tempered martensitic structures. High alloy steel T91 strengthened by several methods, they are sub-boundary or boundary hardening, dislocation hardening and addition to solution hadening. Two different types of grain boundaries 'carbonitrides', and 'intermetallic' presents in this work. [13].



(a) Weld metal

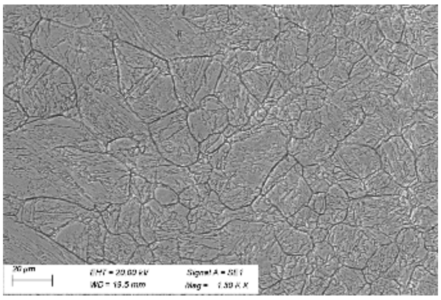


(b) Weld metal

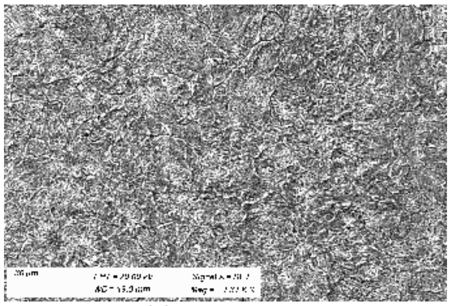
Figure 7 SEM image Argon weld Specimen

Figure 7 (a) shows the image of SEM examinations for argon gas weld specimen. The image magnification ranges of 1.28 KX and 20 µm. The weld metal revealed that grain structure in weld zone is a mixture of ferrite and austenite and the welded region for SEM examination revealed that, the structure is dendritic grains tempered martensite and retained ferrite area. The image shows that the weld metal has the columnar grain. Carbides are predominately precipitates in the weld metal. When argon shielding gas is used for ferrite rich weld metal, it reduces the corrosion resistance properties. The structure is of this region is intermetallic, sigma and other precipitates. Figure 7 (b) shows the image of SEM examinations for argon gas weld specimen. The images magnification ranges of 1.31 K X and 30 µm. It has been reported that a more amount of ferrite is produced when argon is using as a shielding gas.

The helium gas weld specimen SEM images are shown in figure 8 (a) and (b) with different magnification ranges. The weld metal structure shows a tempered martensitic structure and weld metal having columnar grain structure. The particles are observed along the martensitic lath and primary austenite grain boundaries. Helium gas has a great heating power and high heat input to weld metal. Therefore, during welding, thermal cycle produces a complex microstructure across the Heat Affected Zone (HAZ) and Weld Metal. So the weld metal shows the tempered martensitic structures in the helium gas weld specimen [14].



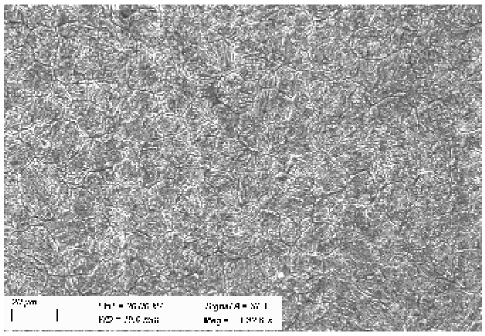
(a) Weld metal



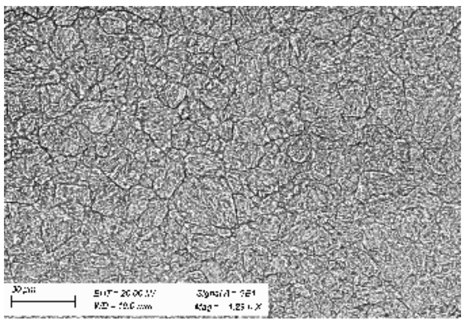
(b) Weld metal

Figure 8: SEM image Helium weld Specimen

SEM for Argon 50% & Helium 50% gas weld specimen shown in figure 9 (a) & (b). The images magnification ranges of 1.30 KX and 20 µm.



(a) Weld Metal



(b) Weld Metal

Figure: 9 SEM image Argon 50% & Helium 50% weld Specimen

It gives more tempered martensite and retained ferrite grain structure. The weld metal grain structures shows tempered martensitic and primary austenite grain boundaries. It provides a suitable cooling rate for transfer from α to γ phase, which improves the impact toughness of the weldment. The figure 9 (a) shows the images of SEM examinations for Argon 50% & Helium 50% weld Specimen. The images magnification ranges of 1.32 KX and 20 μm. It gives more tempered martensite and retained ferrite grain structure than the argon gas weld specimen [15].

4. CONCLUSIONS

In this research, the effects of shielding and purge gases (argon gas, helium gas and a mixture of argon plus helium gases) on the weld properties of a alloy steel (T91) were investigated. Weld specimens were prepared using GTAW process with different gases and the weld characteristics were examined using tensile test, microhardness test, micrographs and SEM. The results were discussed and from the obtained results, the following conclusions are summarized as follows: Deeper penetration and shallow metal deposition were observed in helium gas. The tensile strength was obtained on the Helium gas test specimen. High residual stress was measured in Argon gas specimen. Average hardness value of the argon gas specimen is comparatively high. The microstructure analysis revealed that the weld metals in all specimens are tempered martensite structure. The particles observed in all specimens alongside the primary austenite and martensitic lath grain boundaries. From the results, it was observed that pure helium specimens showed better weld characteristics as compared to other gas compositions.

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ПОБОЉШАЊЕ МЕХАНИЧКИХ СВОЈСТАВА ЛЕГИРАНОГ ЧЕЛИКА ПРИМЕНОМ GTAW СА РАЗЛИЧИТИМ ГАСОВИМА ЗА ПРОЧИШЋАВАЊЕ И ЗАШТИТУ

Г.Б. Јозеф, А.Ј. Рајан, Г. Муругесан, Р. Прабхакаран, Ј. Јевахан, Г. Магешваран

Цеви од феритног челика Т91 су одабране за заваривање због отпорности на високе температуре, механичка својства, компатибилности са хемијским супстанцама и добре заварљивости. Циљ пројекта је био изналажење параметара близу оптималних са

применом одговарајућег прочишћавајућег гаса код GTAW заваривања цеви од T91 материјала. Квалитет и продуктивност завареног споја највише зависе од параметара заваривања. Савршени лук се добија током заваривања када заваривач користи оптималне параметре заваривања. Састав заштитног гаса има значајан утицај на квалитет шава, али маргинални утицај на дубину продирања алата код купатила при заваривању. Припремљена су три узорка са оптимизираним параметрима прочишћавајућих гасова у следећем саставу: хелијум 100%, аргон 100%, аргон 50% + хелијум 50% за заваривање цеви T91 дебљине 2,9мм и електродом ER505.

ANNEX 1

Table 2: Welding parameters (GTAW)

Gas Used Shielding /Purging	Voltage [V]	Travel Speed [mm/mint]	Current [Amp]	Purge gas [lpm]	Shield Gas [lpm]	Dia of wire [mm]
Argon Gas [Ar]	12	32	60	6	10	Ø 1.6
Helium Gas [He]	11	28	50	6	8	Ø 1.6
Argon + Helium	10	30	55	Ar - 3 He – 3	Ar - 5 He - 5	Ø 1.6